Development of the CERES Flux-by-cloud type simulator

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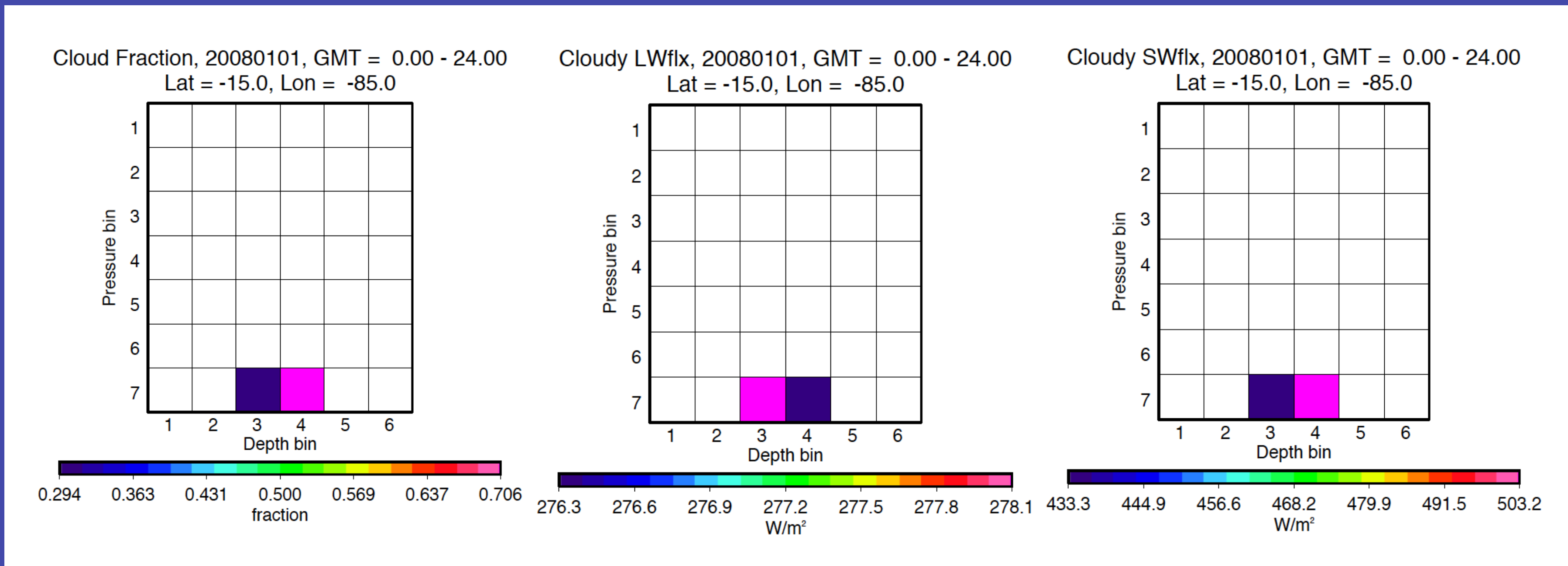
What is the Flux-by-cloud type product?

- Assigns a flux to each observed ISCCP cloud type within a region.
- For each 1°x1° region between 60° S and 60° N, each daytime footprint is placed into 1-3 p_c-τ ISCCP-like categories (3 categories would be the case of a footprint with two cloud levels as well as clear pixels).
- For the footprints with a single cloud type, the standard SSF flux is added to that p_c-τ category.
- For footprints with multiple cloud levels, narrowband-to-broadband radiance conversions are performed for each cloud level.
- Broadband radiances are converted to fluxes using ADMs.

Sample Flux-by-cloud type plots

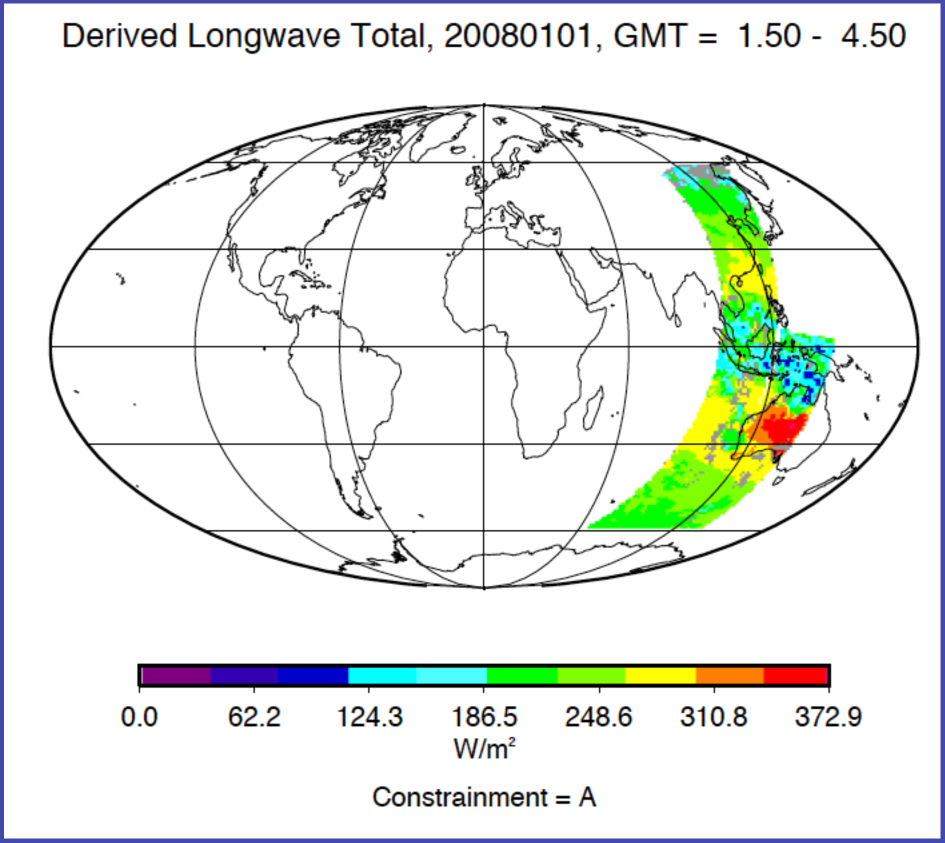
Cloud fraction | LW flux | SW flux



Here, Terra passed over the SE Pacific on Jan 1 2008, and there were two p_c-τ cloud types (p_c=800-1000 hPa, τ=3.6-9.4 and τ=9.4-23). The optically thicker part of the region has more outgoing SW, and slightly less OLR.

What is a simulator?

- Put simply, a simulator is meant to replicate what a space-based instrument would measure if it flew above a GCM or other model on the temporal and spatial scales of the measurements.



Motivation for flux-by-cloud type simulator

- Cloud properties and fluxes/albedos will be matched within 1.5 hours to the closest CERES overpass, which is important because of the large diurnal cycles in cloud fraction, τ, and p_c in many areas.
- Breaking out the flux by cloud type can help isolate physical parameterizations that are problematic (e.g., convective clouds, boundary-layer parameterizations, or processes involving surface albedo), and provide a test for new parameterizations.
- Diagnoses using flux-by-cloud type combined with frequency of occurrence can also help determine whether an unrealistically small or large occurrence of a given cloud type has an important radiative impact for a given region.

Outline of Simulator Approach

Read in data at GCM grid size

→

Run cloud generator and cloud property simulator to produce atmospheric subcolumns

→

Classify subcolumns into p_c-τ cloud types

→

Perform radiative transfer on a subset of subcolumns in each type

Cloud Generator

•GCM grid cells are much larger (~1°×1°, or ~10000 km^2) than MODIS pixels (~8 km^2 spacing), so the grid cells are first split into enough "pseudo-pixel" subcolumns so that they represent a comparable area.

•The subcolumns are assigned a binary (0 or 1) cloud fraction at each vertical level using a cloud generator (Klein and Jakob 1999; Webb et al. 2001) with the maximum-random overlap assumption.

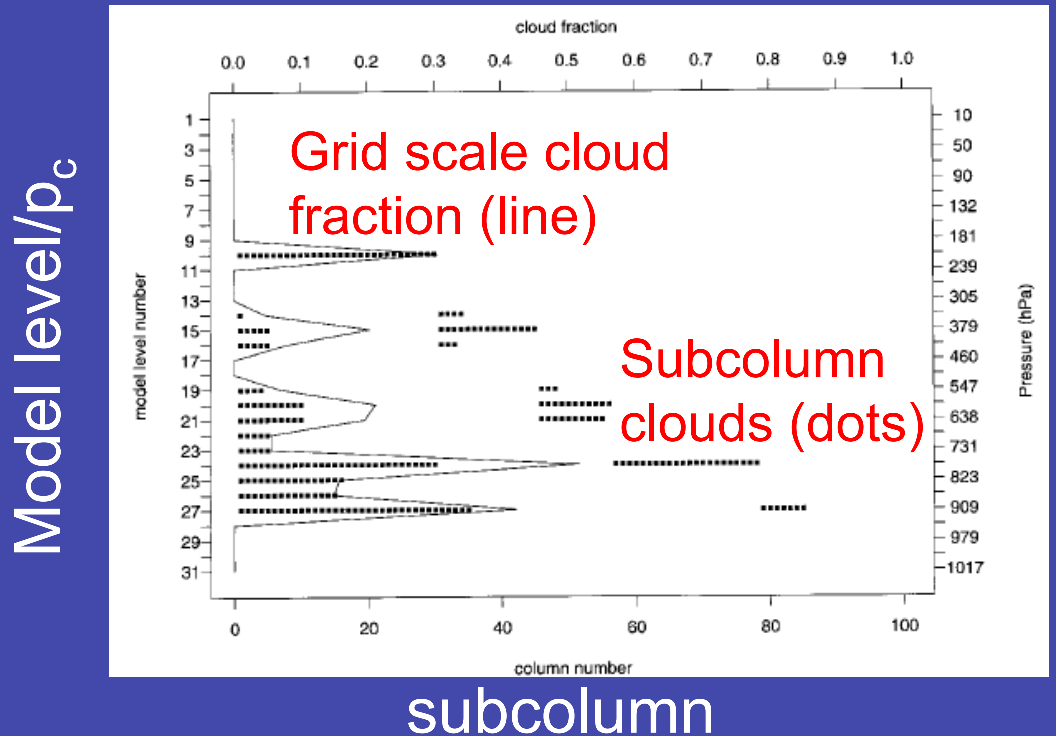


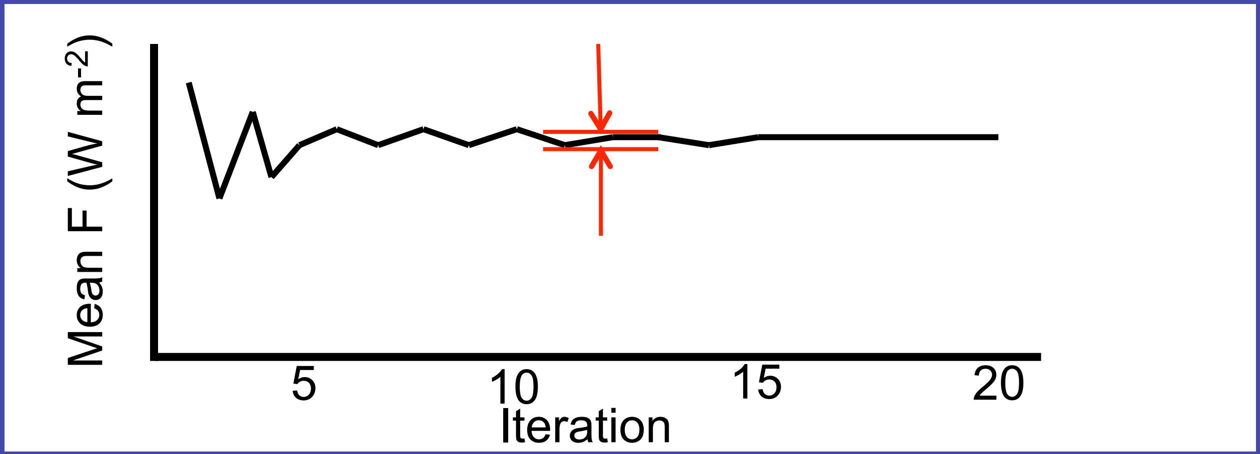
Figure from Klein and Jakob 1999

Langley Fu-Liou Model

•Fu-Liou radiative transfer model is run for at least 5 profiles for each p_c-τ cloud type, obtaining mean broadband LW and SW fluxes, $F_{LW}(5)$, $F_{SW}(5)$.

•Meteorological conditions (temperature, ozone concentration, water vapor mixing ratio, surface albedo, solar zenith angle) are considered horizontally homogeneous over each GCM grid cell.

•Computationally expensive to calculate radiative transfer on every column, so it is performed on additional profiles until mean flux F(n+1) does not change much relative to F(n).



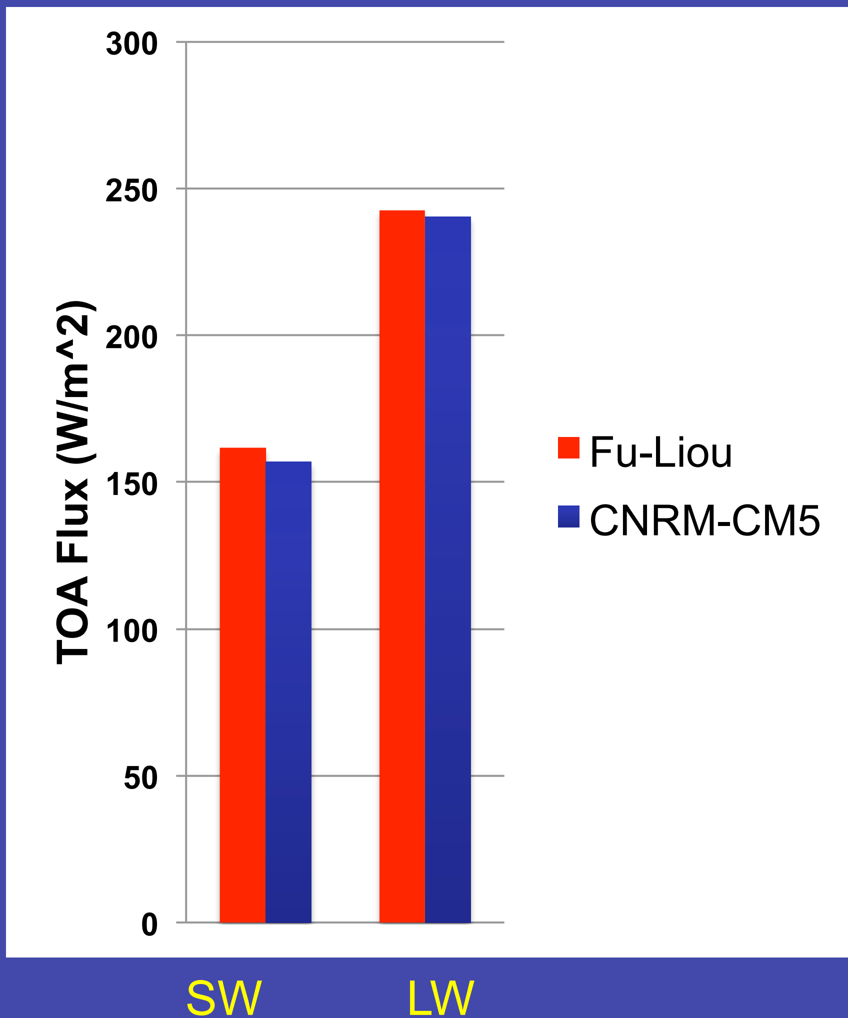
TOA Radiation test

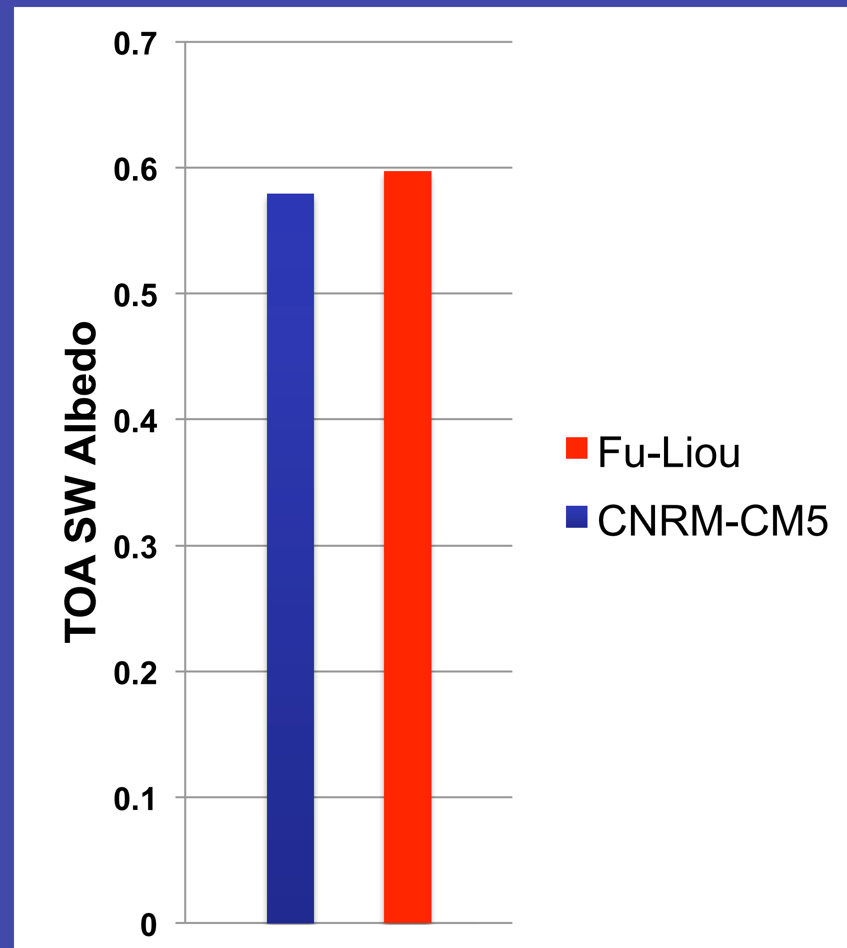
- Meant to verify that RT model produces similar TOA LW and SW fluxes as CMIP5 GCMs for simple cases.
- Pick cases where there is a single, overcast layer of liquid water cloud over ocean, and apply the Fu-Liou model to them.
- Profile inputs: p, T, q_v, O_3.
- Surface inputs: skin temperature, albedo, and emissivity.
- Cloud-layer inputs: top and base pressure, effective radius, optical depth
- I found and ran several cases for both the CNRM-CM5 and UKMO-HadGEM2A models.

Single-Layer overcast water cloud: CNRM-CM5 Case 1

- Located over Southern Ocean (62.3 S, 135 E)
- r_e derived from Benedetti and Janiskova: 10.9 μm
- τ derived from same equation used in Fu-Liou code: 24.1
- p_{base} = 983 hPa, p_{top} = 880 hPa
- Albedo derived from surface (SW_{up}/SW_{down}): 0.061
- Surface emissivity from ($LW_{up}/\sigma_{sb}T^4$): 0.994
- Cosine of SZA: 0.193

Single-Layer overcast water cloud: CNRM-CM5 Case 1

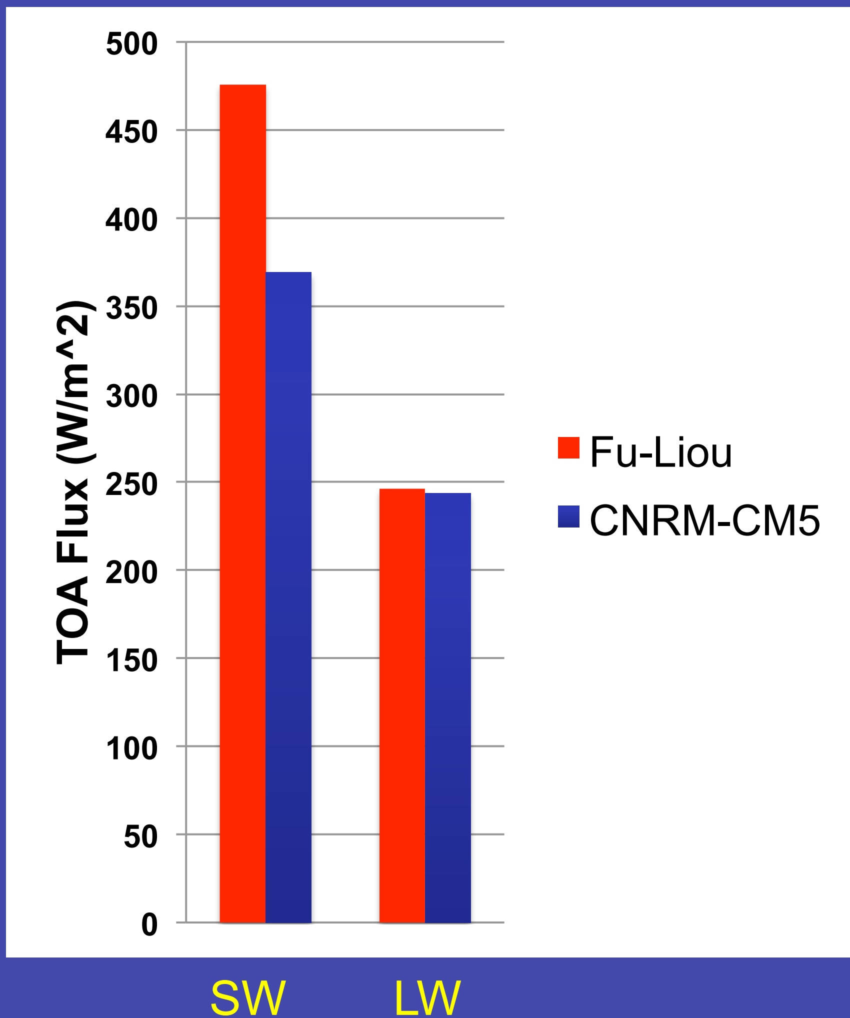


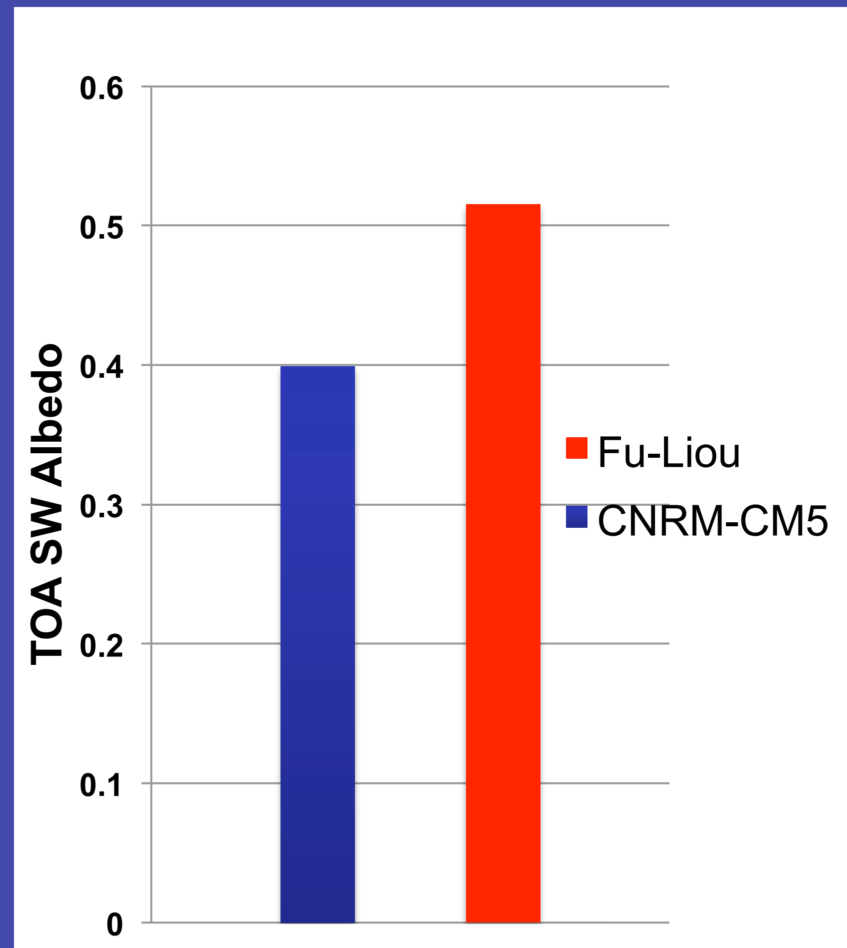


Single-Layer overcast water cloud: CNRM-CM5 Case 2

- Located over Southern Ocean (53.9 S, 118.1 E)
- r_e: 11.9 μm
- τ: 19.3
- p_{base} = 983 hPa, p_{top} = 920 hPa
- Surface albedo: 0.061
- Surface emissivity: 0.997
- Cosine of SZA: 0.658

Single-Layer overcast water cloud: CNRM-CM5 Case 2

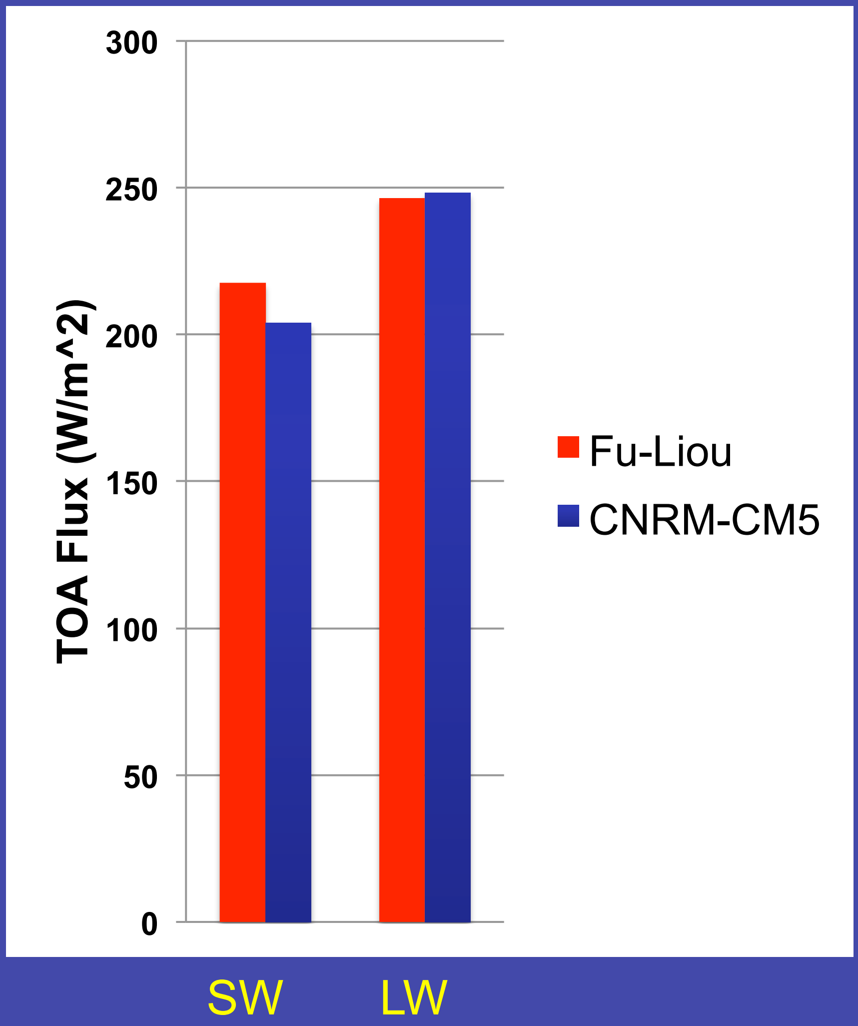


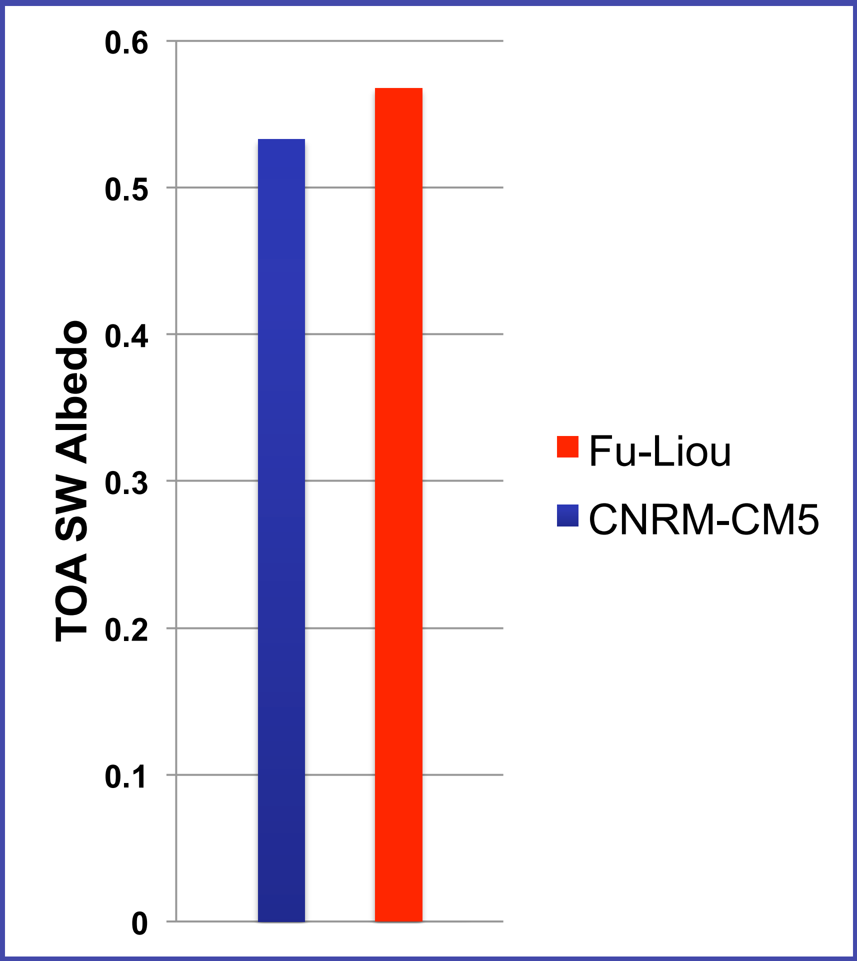


Single-Layer overcast water cloud: CNRM-CM5 Case 2 (t+3hr)

- Same inputs as previous Case 2, but using radiation fields at 3 hours past the time stamp of the clouds, since downward TOA solar radiation is an average of 3 hours previous to time stamp.
- Cosine of SZA: 0.272

Single-Layer overcast water cloud: CNRM-CM5 Case 2 (t+3hr)

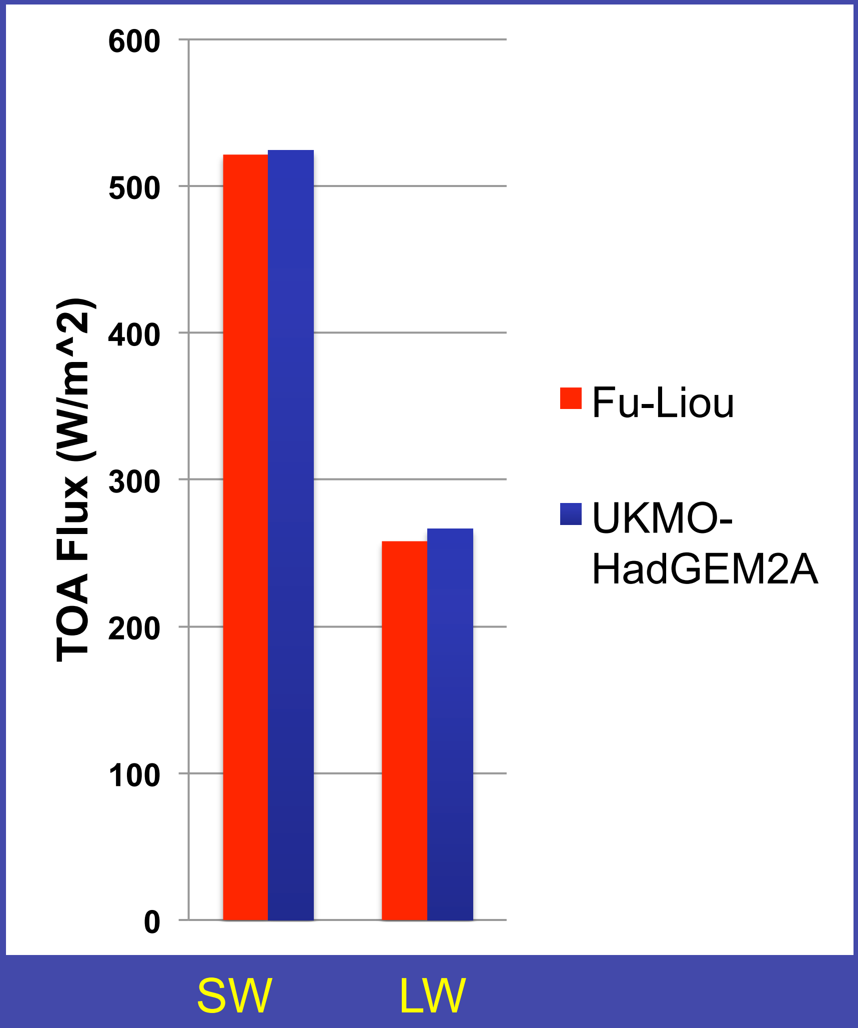


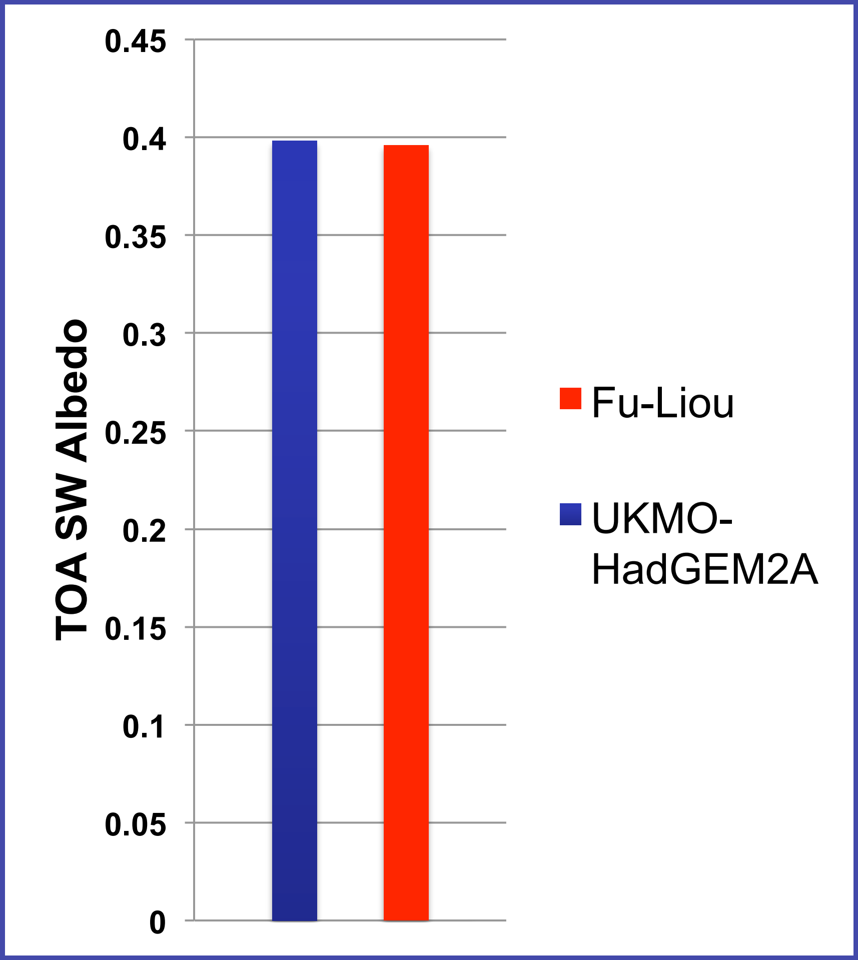


Single-Layer overcast water cloud: Case 1 (UKMO-HadGEM2A)

- Located over Southern Indian Ocean (36.3 S, 99.4 E)
- r_e from model output: 15.9 μm
- τ from model output: 14.3
- p_{base} = 969 hPa, p_{top} = 928 hPa
- SW albedo derived from surface (SW_{up}/Sw_{down}): 0.062
- Surface emissivity from ($LW_{up}/\sigma_{sb}T^4$): 0.9998
- Cosine of SZA: 0.933

Single-Layer overcast water cloud: Case 1 (UKMO-HadGEM2A)

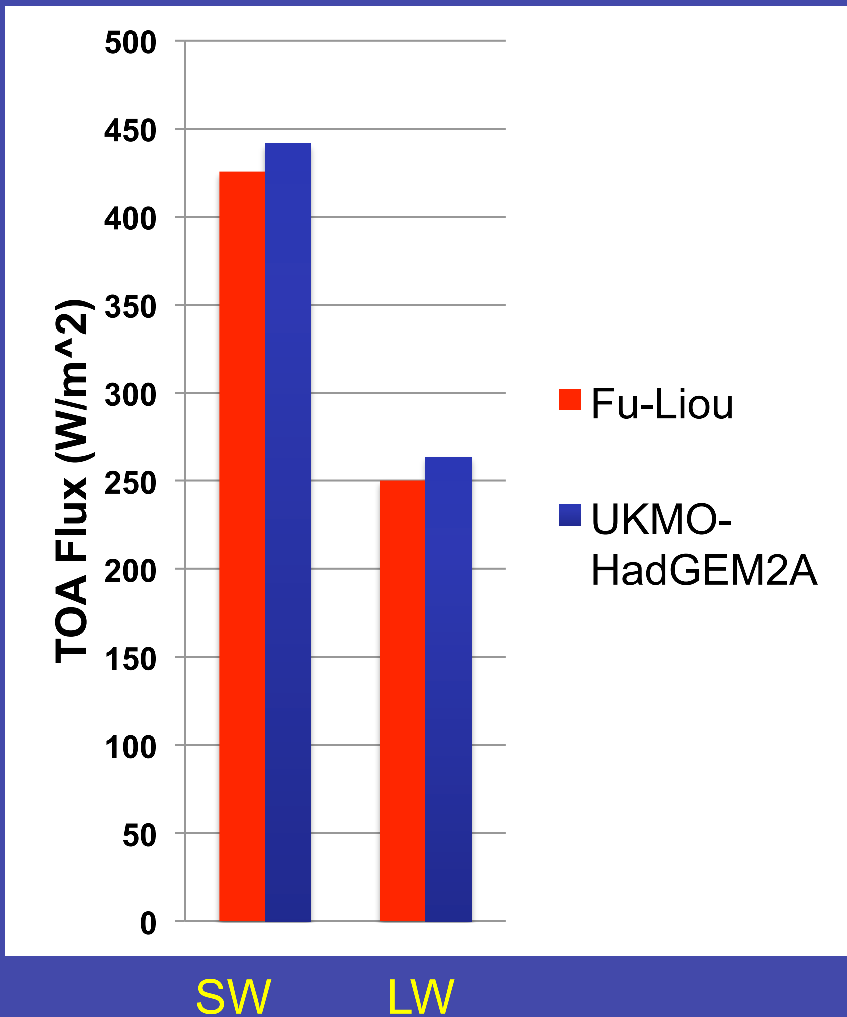


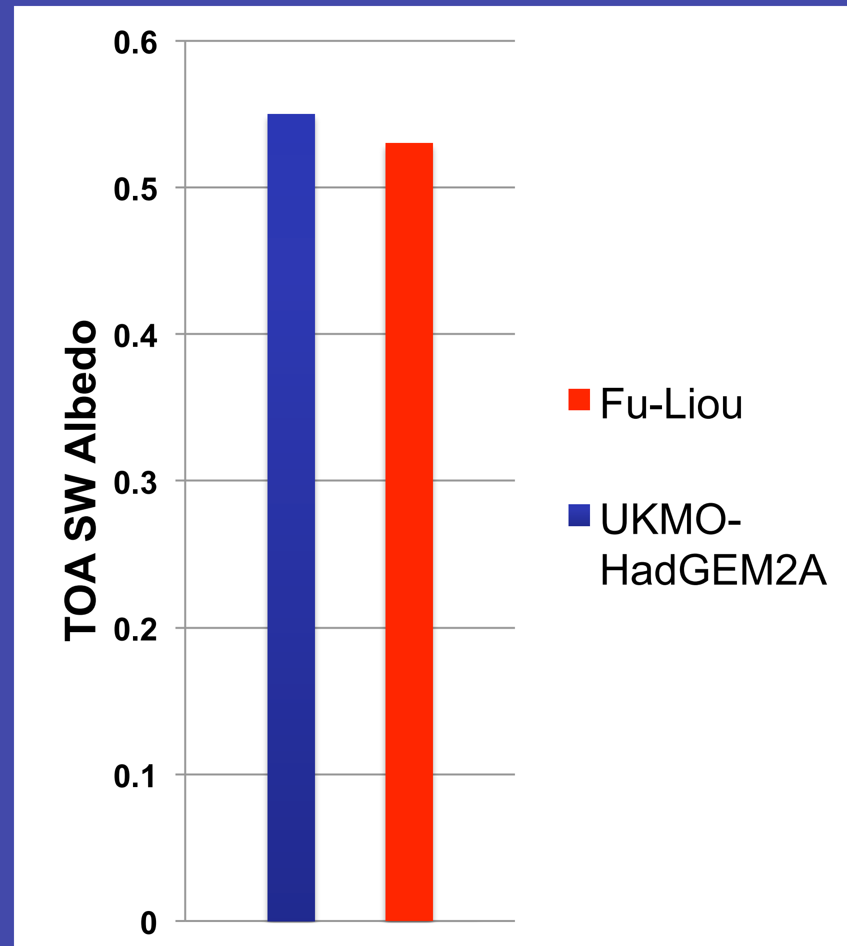


Single-Layer overcast water cloud: Case 2 (UKMO-HadGEM2A)

- Located over Western Pacific Ocean (25 N, 138.75 E)
- r_e from model output: 14.1 μm
- τ from model output: 19.0
- p_{base} = 936 hPa, p_{top} = 884 hPa
- SW albedo derived from surface (SW_{up}/Sw_{down}): 0.064
- Surface emissivity from ($LW_{up}/\sigma_{sb}T^4$): 0.9998
- Cosine of SZA: 0.569

Single-Layer overcast water cloud: Case 2 (UKMO-HadGEM2A)





Summary

- The CERES flux-by-cloud type data product assigns fluxes to ISCCP (p_c, τ) cloud categories.
- As a first step towards building a simulator, the TOA fluxes associated with single-layer water clouds were compared between the Langley Fu-Liou RT model and CNRM-CM5 and UKMO-HadGEM-2A GCM output.
- Fu-Liou OLR is close to that of CNRM-CM5 output, but TOA shortwave albedo tends to be significantly higher, perhaps because of incorrect conversion of LWC to τ, or timestamp issues.
- Fu-Liou TOA shortwave albedo is close to that of UKMO-HadGEM2A output, but OLR tends to be lower, by as much as 5%.

Extra slides

Future Work

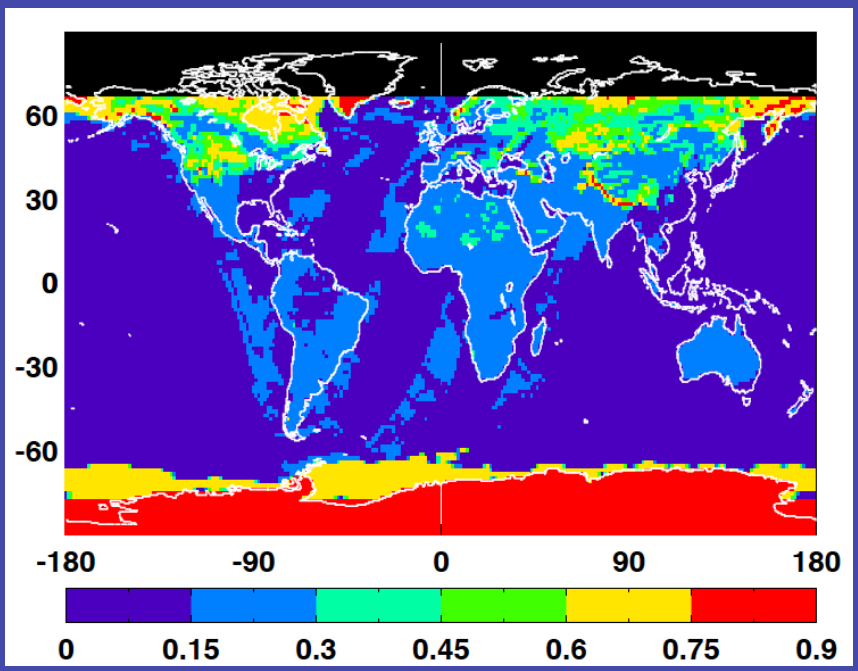
- Apply simulator to models with 3-hourly IPCC CFMIP (Cloud Feedback Model Intercomparison Project) output.
- We will compare flux-by-cloud type output on monthly or greater timescales, since fluctuations associated with weather are impossible for climate models to reproduce.
- Use albedo rather than flux for SW because up to 1.5 hours of temporal mismatch will cause significant flux differences.
- Will run the simulator a limited number of times with radiative transfer applied to all subcolumns in order to verify that the limited number used will be a good approximation.

Surface Albedo and Emissivity

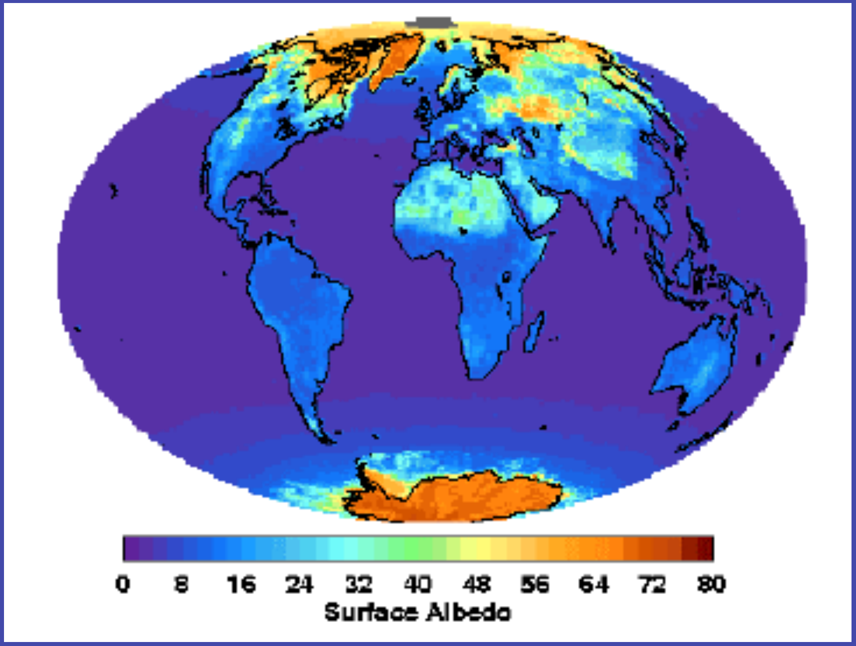
- Neither quantity is provided in the model output.
- For albedo, use ratio of SW_{up}/SW_{down} at the surface.
- For surface emissivity, use ratio of $LW_{down}/\sigma T_s^4$ at the surface.

Surface Albedo

CNRM Jan 2008 surface albedo from surface fluxes

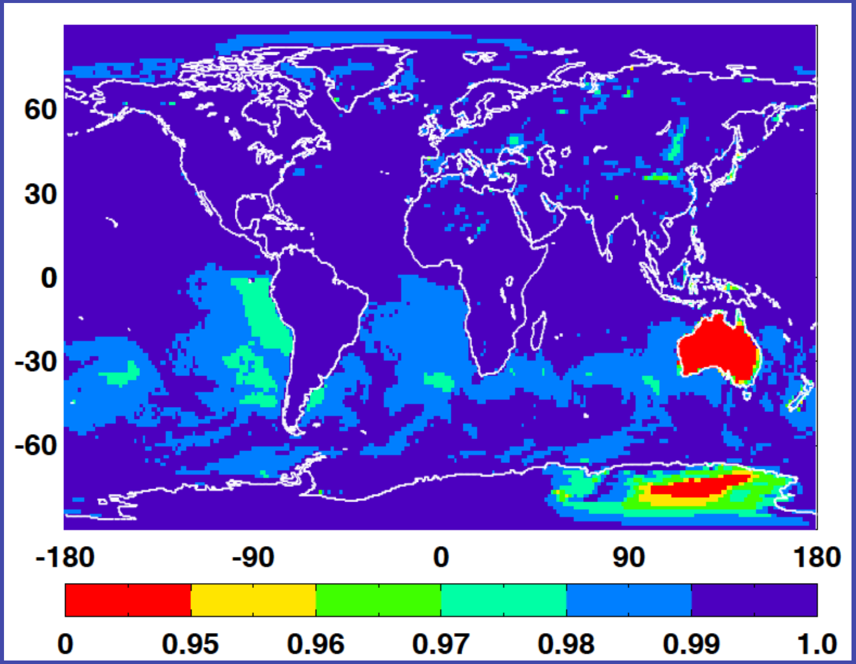


CERES/SARB Mar 2000 surface albedo from Rutan et al. (2006)

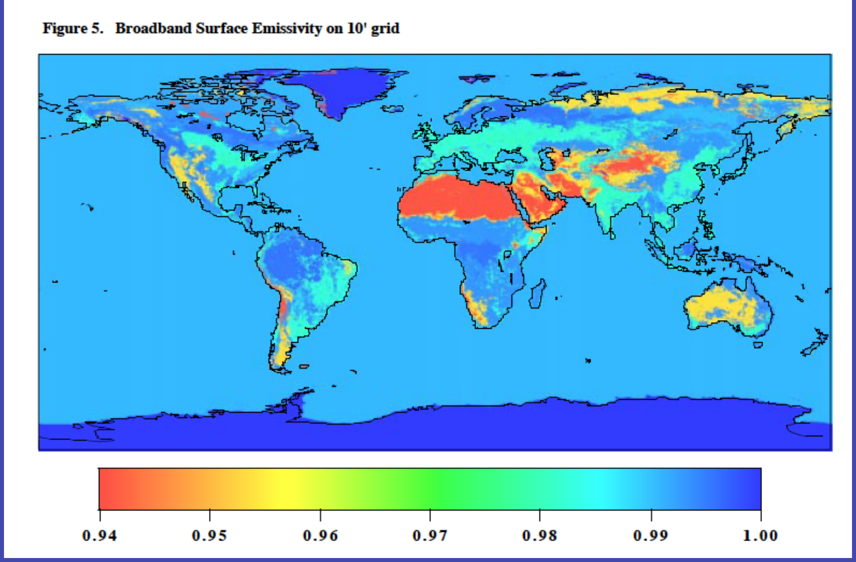


Surface Emissivity

CNRM Jan 2008 surface albedo from surface LW up, skin temp.



Surface broadband emissivity from Wilber et al. (1999)



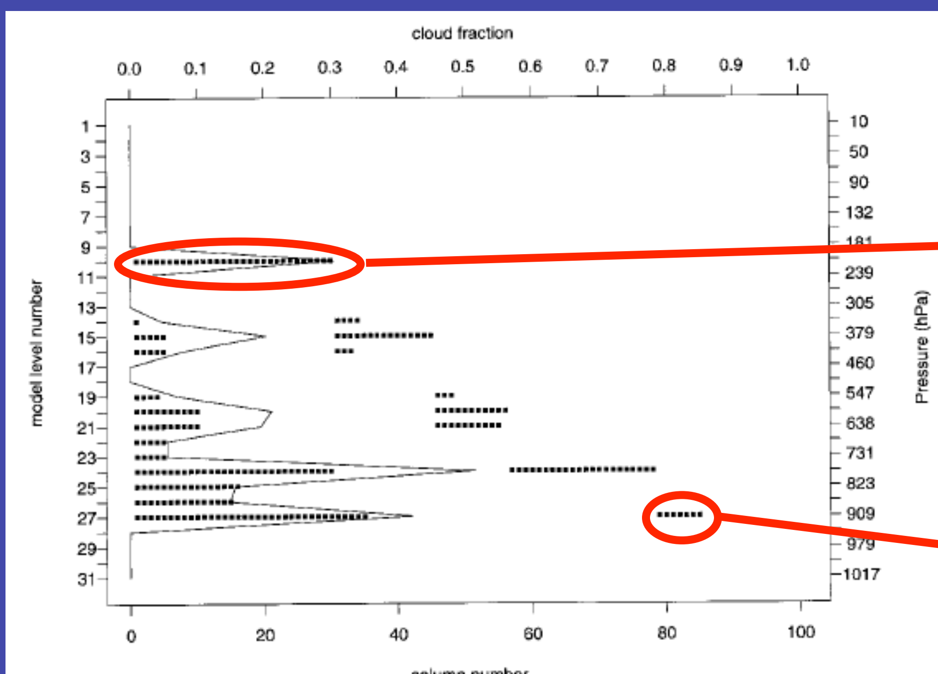
CNRM LW emissivities seem higher than those from Wilber et al. (1999), especially over the Sahara desert and East Antarctica. Some values over the Americas are actually over 1.0.

Cloud Property Simulator

•The MODIS simulator from the CFMIP Observational Simulator Package (COSP) is used to derive cloud properties.

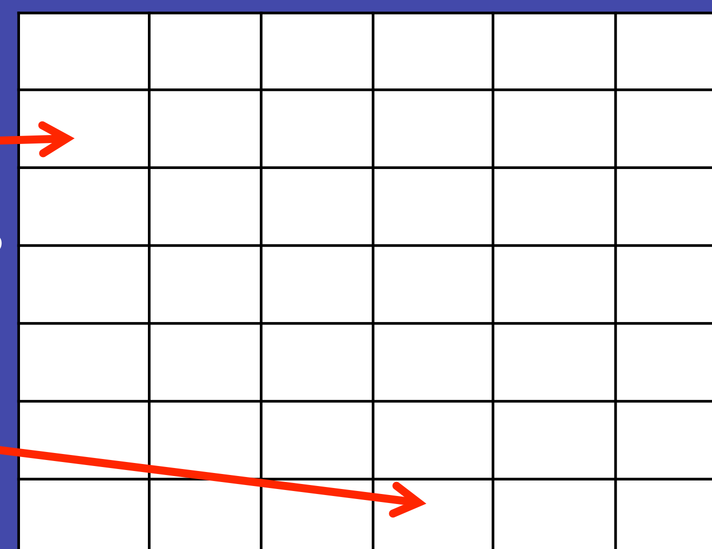
•Each cloudy subcolumn is assigned to one of the 42 p_c-τ cloud types based on the p_c and τ values obtained from the MODIS simulator, with clear columns representing a 43rd type.

Model level/p_c



subcolumn

p_c



τ

CERES Footprint

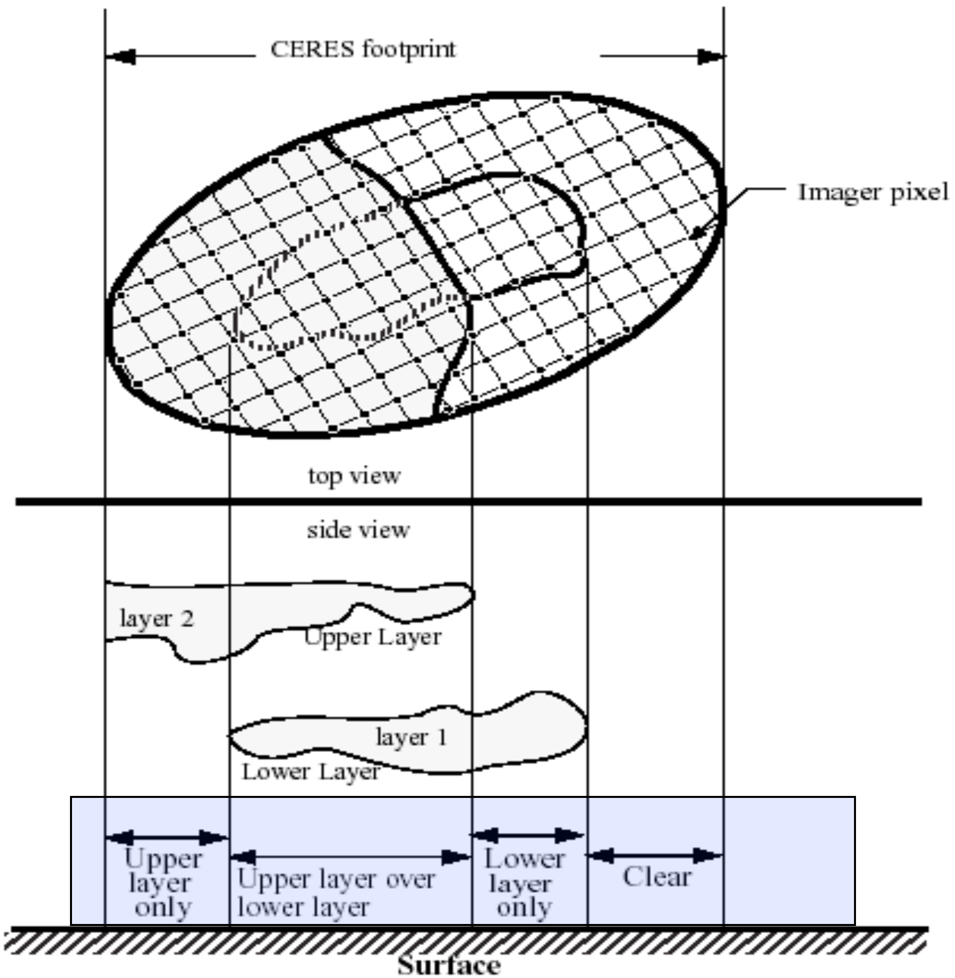


Figure 4-10. CERES Clear/layer/overlap illustration

3 parts but one total flux for a footprint:

- Upper layer
- Lower layer
- Clear

After processing, we will assign a flux value to each part.

Steps involved with offline Flux-by-cloud type Simulator

- Read in required variables: profiles of temperature, water vapor, cloud fraction, etc.
- For those grid cells that match the FBCT product (daytime, 60°S-60°N, closest model output time to Terra/ Aqua overpass), use MODIS cloud property simulator at fine (~8km^2) resolution to produce ~1000 cloudy columns.
- These columns are grouped into p_c-τ categories.

Note on RT calculations

- When assigning the flux to a CTP-τ bin, we use the retrieved CTP and τ from the MODIS simulator, but the flux is based on the actual cloud profile.
- For example, a column with a very thin cloud could be counted as “clear”, but its retrieved fluxes would take the cloud into account.

Benefits of this approach

- Cloud properties and fluxes/albedos are matched within 1.5 hours to the closest CERES overpass, which is important because of the large diurnal cycles in cloud fraction, τ, and p_c in many areas.
- Breaking out flux by cloud type can help isolate physical parameterizations that are problematic, and provide a test for new parameterizations.

What’s in the CFMIP archive

- 7 participating modeling centers: CCCMA (Canada), CNRM (France), LASG (China), MRI (Japan), MPI-M (Germany), MOHC (UK), and NCAR.
- Only three of the models have 3-hourly profile data of air temperature, cloud amount, mass fraction of water/ice: CNRM, MRI, and MOHC. MRI doesn’t seem to have stratiform cloud amount?
- Water vapor profiles are included at a six-hourly interval for all three models.
- Effective radii of water/ice, tau profiles and emissivity are included for MRI, MOHC only.
- 3-hourly land and sea ice skin temperature seems to only be included for CNRM, MRI only. Only MRI has 3-hourly SST, but all models have monthly mean skin temperature, which should be OK for SST.

Single-Layer overcast water cloud: CNRM-CM5 Case 1

Variable	CNRM output	Fu-Liou output
TOA SW down	270.9 W m^{-2}	270.9 W m^{-2}
TOA SW up	156.9 W m^{-2}	161.6 W m^{-2}
TOA SW albedo	0.579	0.597
TOA OLR	242.6 W m^{-2}	240.3 W m^{-2}
SFC SW down	35.0 W m^{-2}	37.1 W m^{-2}
SFC SW up	2.1 W m^{-2}	2.3 W m^{-2}
SFC LW up	323.5 W m^{-2}	325.3 W m^{-2}

Single-Layer overcast water cloud: CNRM-CM5 Case 2

Variable	CNRM output	Fu-Liou output
TOA SW down	924.9 W m^{-2}	924.9 W m^{-2}
TOA SW up	369.2 W m^{-2}	475.8 W m^{-2}
TOA SW albedo	0.399	0.515
TOA OLR	243.6 W m^{-2}	246.5 W m^{-2}
SFC SW down	369.4 W m^{-2}	240.6 W m^{-2}
SFC SW up	22.5 W m^{-2}	14.6 W m^{-2}
SFC LW up	335.5 W m^{-2}	336.4 W m^{-2}

Single-Layer overcast water cloud: Case 2 (CNRM, t+3hr)

Variable	CNRM output	Fu-Liou output
TOA SW down	382.7 W m^{-2}	382.7 W m^{-2}
TOA SW up	203.9 W m^{-2}	217.5 W m^{-2}
TOA SW albedo	0.533	0.568
TOA OLR	248.2 W m^{-2}	246.5 W m^{-2}
SFC SW down	74.5 W m^{-2}	67.3 W m^{-2}
SFC SW up	4.5 W m^{-2}	4.1 W m^{-2}
SFC LW up	335.5 W m^{-2}	336.4 W m^{-2}

Single-Layer overcast water cloud: Case 3

- Located over Southern Ocean (52.5 S, 118.1 E)
- r_e: 11.6 μm
- τ: 23.0
- p_{base} = 1005 hPa, p_{top} = 922 hPa
- SW albedo: 0.061
- Surface emissivity: 0.998
- Cosine of SZA: 0.265

Single-Layer overcast water cloud: Case 3

Variable	CNRM output	Fu-Liou output
TOA SW down	372.5 W m^{-2}	372.5 W m^{-2}
TOA SW up	197.1 W m^{-2}	215.9 W m^{-2}
TOA SW albedo	0.529	0.579
TOA OLR	251.1 W m^{-2}	248.0 W m^{-2}
SFC SW down	69.4 W m^{-2}	57.5 W m^{-2}
SFC SW up	4.2 W m^{-2}	3.5 W m^{-2}
SFC LW up	337.7 W m^{-2}	338.3 W m^{-2}

Single-Layer overcast water cloud: CNRM Case 4 (t+1)

- Located over Southern Ocean (52.3 S, 123.8 E)
- r_e: 11.6 μm
- τ: 33.3
- p_{base} = 1004 hPa, p_{top} = 881 hPa
- SW albedo: 0.061
- Surface emissivity: 0.998
- Cosine of SZA: 0.409

Single-Layer overcast water cloud: CNRM (Case 4, t+1)

Variable	CNRM output	Fu-Liou output
TOA SW down	574.7 W m^{-2}	574.7 W m^{-2}
TOA SW up	317.1 W m^{-2}	349.8 W m^{-2}
TOA SW albedo	0.552	0.609
TOA OLR	255.4 W m^{-2}	251.7 W m^{-2}
SFC SW down	110.2 W m^{-2}	81.0 W m^{-2}
SFC SW up	6.8 W m^{-2}	4.9 W m^{-2}
SFC LW up	342.6 W m^{-2}	342.8 W m^{-2}

Met Office Hadley Centre Model

- Profile inputs: p, T (3hr), q_v (6hr) are present, O_3 does not appear to be (could use standard atmosphere?)
- Surface inputs: Skin temperature available every 3hr, albedo and emissivity derivable from (3-hourly) surface fluxes.
- Cloud inputs: Stratiform and convective cloud cover, stratiform and convective water and ice content, stratiform and convective optical depth, stratiform and convective effective radius for water and ice.

Single-Layer overcast water cloud: Case 1 (UKMO-HadGEM2A)

Variable	UKMO output	Fu-Liou output
TOA SW down	1317.9 W m^{-2}	1317.9 W m^{-2}
TOA SW up	524.3 W m^{-2}	521.5 W m^{-2}
TOA SW albedo	0.398	0.396
TOA OLR	266.5 W m^{-2}	258.2 W m^{-2}
SFC SW down	508.7 W m^{-2}	497.5 W m^{-2}
SFC SW up	31.3 W m^{-2}	30.9 W m^{-2}
SFC LW up	400.5 W m^{-2}	400.4 W m^{-2}

Single-Layer overcast water cloud: Case 2 (UKMO-HadGEM2A)

Variable	UKMO output	Fu-Liou output
TOA SW down	802.8 W m^{-2}	802.8 W m^{-2}
TOA SW up	441.4 W m^{-2}	425.6 W m^{-2}
TOA SW albedo	0.550	0.530
TOA OLR	263.7 W m^{-2}	250.4 W m^{-2}
SFC SW down	195.6 W m^{-2}	195.7 W m^{-2}
SFC SW up	12.5 W m^{-2}	12.5 W m^{-2}
SFC LW up	442.8 W m^{-2}	442.6 W m^{-2}

Single-Layer overcast water cloud: Case 3 (UKMO)

- Located over Southern Ocean (41.25 S, 120 E)
- r_e from model output: 17.1 μm
- τ from model output: 4.5
- p_{base} = 958 hPa, p_{top} = 935 hPa
- SW albedo derived from surface (SW_{up}/Sw_{down}): 0.049
- Surface emissivity from ($LW_{up}/\sigma_{sb}T^4$): 0.9999
- Cosine of SZA: 0.928

Single-Layer overcast water cloud: Case 3 (UKMO)

Variable	UKMO output	Fu-Liou output
TOA SW down	1309.8 W m^{-2}	1309.8 W m^{-2}
TOA SW up	284.1 W m^{-2}	297.2 W m^{-2}
TOA SW albedo	0.217	0.227
TOA OLR	256.9 W m^{-2}	249.0 W m^{-2}
SFC SW down	823.3 W m^{-2}	793.8 W m^{-2}
SFC SW up	40.3 W m^{-2}	38.9 W m^{-2}
SFC LW up	381.0 W m^{-2}	380.9 W m^{-2}